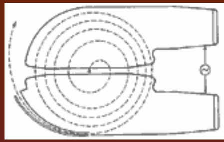
Introduction to System Safety in Research Accelerators

Safety Systems

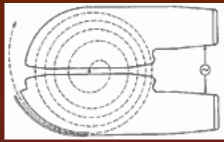
USPAS

June 2004



Outline

- ❖ Logistics
- ❖ Course Overview
- ❖ Course Outline
- ❖ Accelerator Basics



Logistics

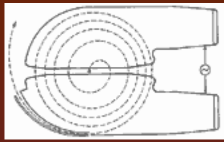
Class hours

- Morning 9-10:45
- Break 10:45-11:00
- Computer 11-12 (Tue-Thurs)
- Lunch 12-1:30
- Afternoon 1:30-4:30

Material

“Reliability, Maintainability, and Risk”, David Smith

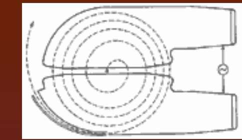
Handouts



Homework

Selected exercises from Smith

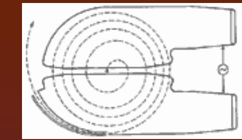
Handouts



Course Outline

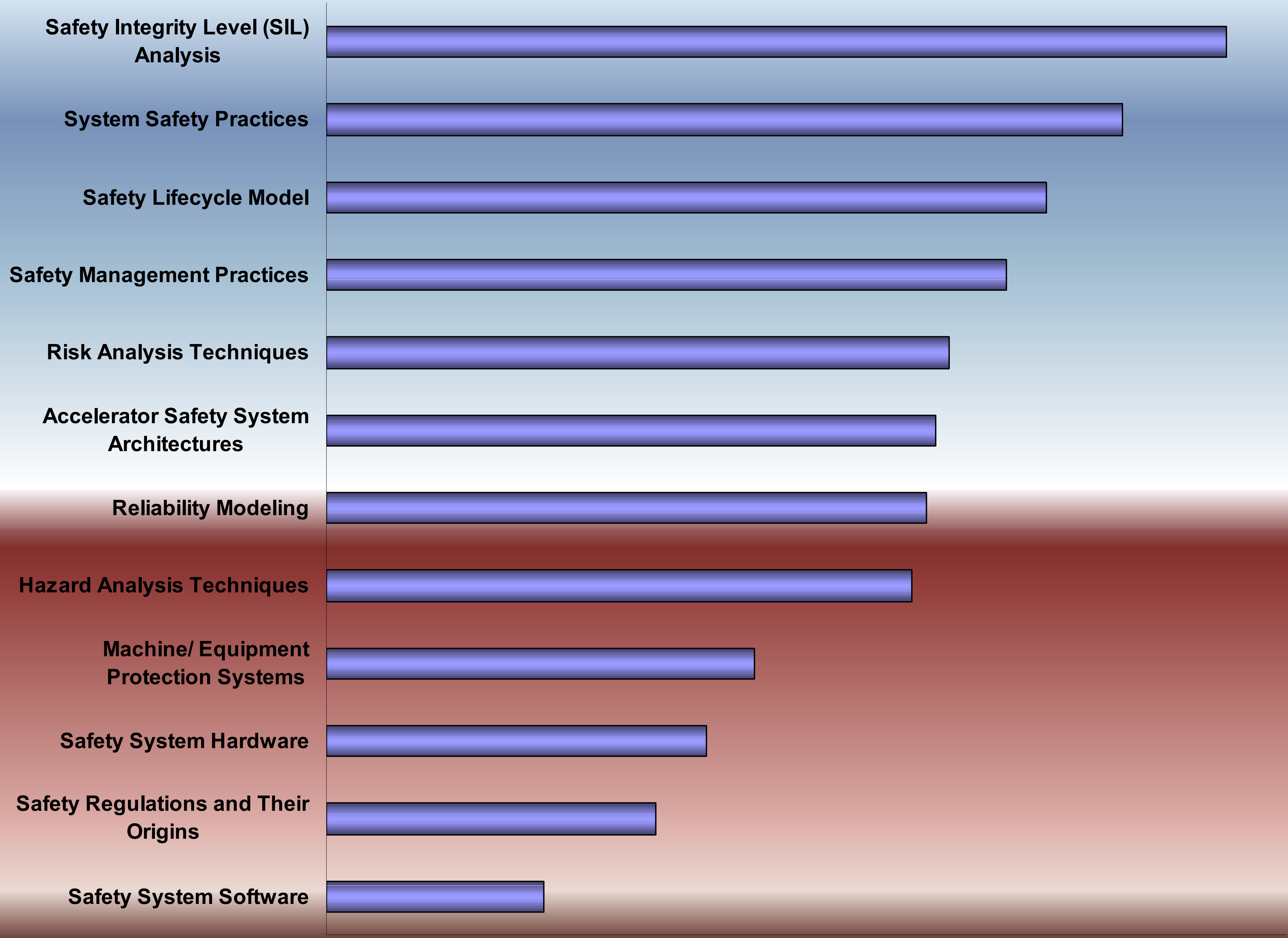
Intent:

It is the intent of this class to communicate a basic knowledge about safety systems used at accelerator labs. One should leave the class knowing the basic steps required for the development of a safety system and the system plan. The class is intended not only to teach basic technical skills such as reliability evaluation but also a greater context in which safety systems are developed. To that end, the class includes a significant amount of material on system safety programs, accelerator regulatory requirements, and what is considered good practice among accelerator management and safety professionals.

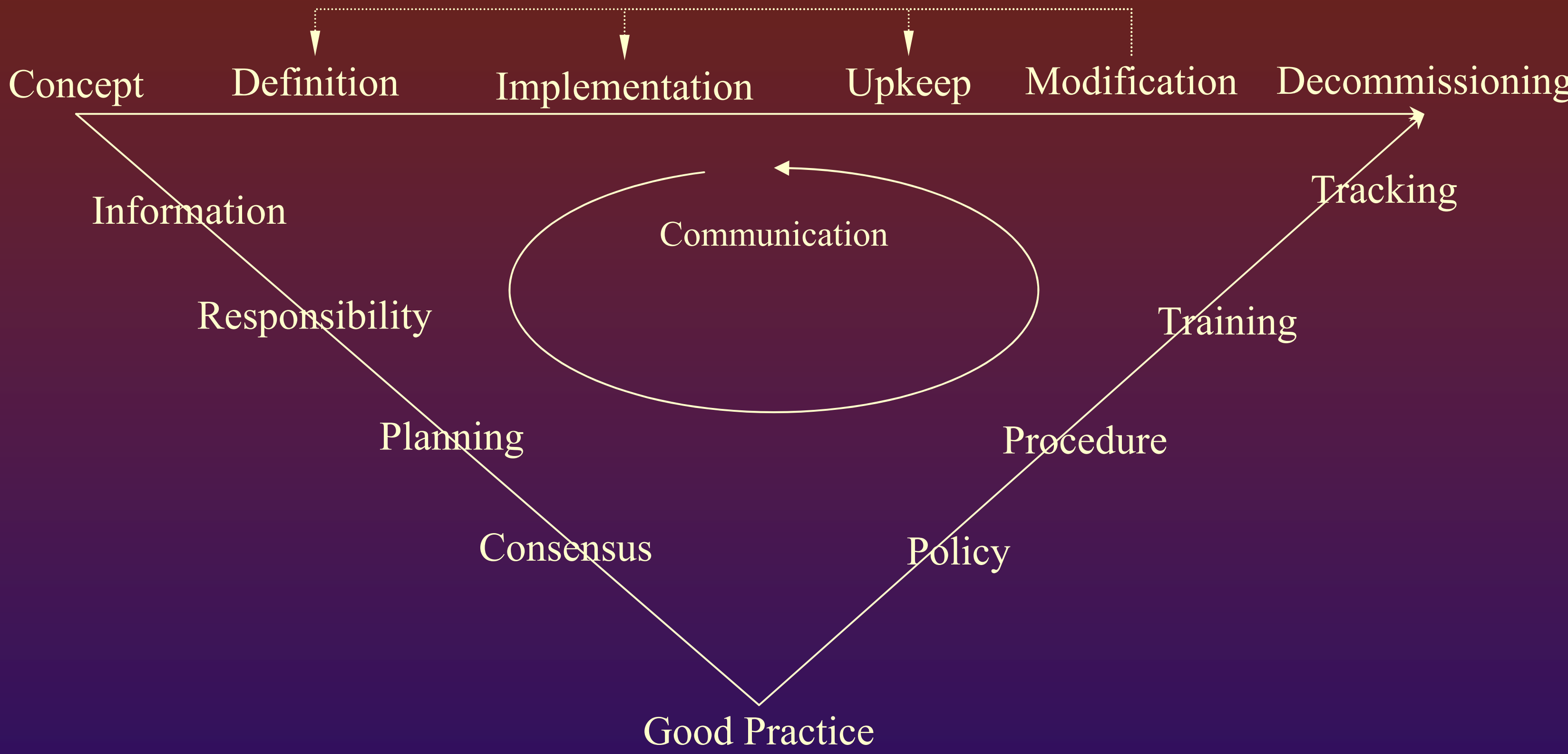


Scope

- This class is intended to address hazards associated with operation of particle accelerator systems. It does not specifically address normal industrial hazards common to all workplaces.


Safety Integrity Level (SIL) Analysis
System Safety Practices
Safety Lifecycle Model
Safety Management Practices
Risk Analysis Techniques
Accelerator Safety System Architectures
Reliability Modeling
Hazard Analysis Techniques
Machine/ Equipment Protection Systems
Safety System Hardware
Safety Regulations and Their Origins
Safety System Software

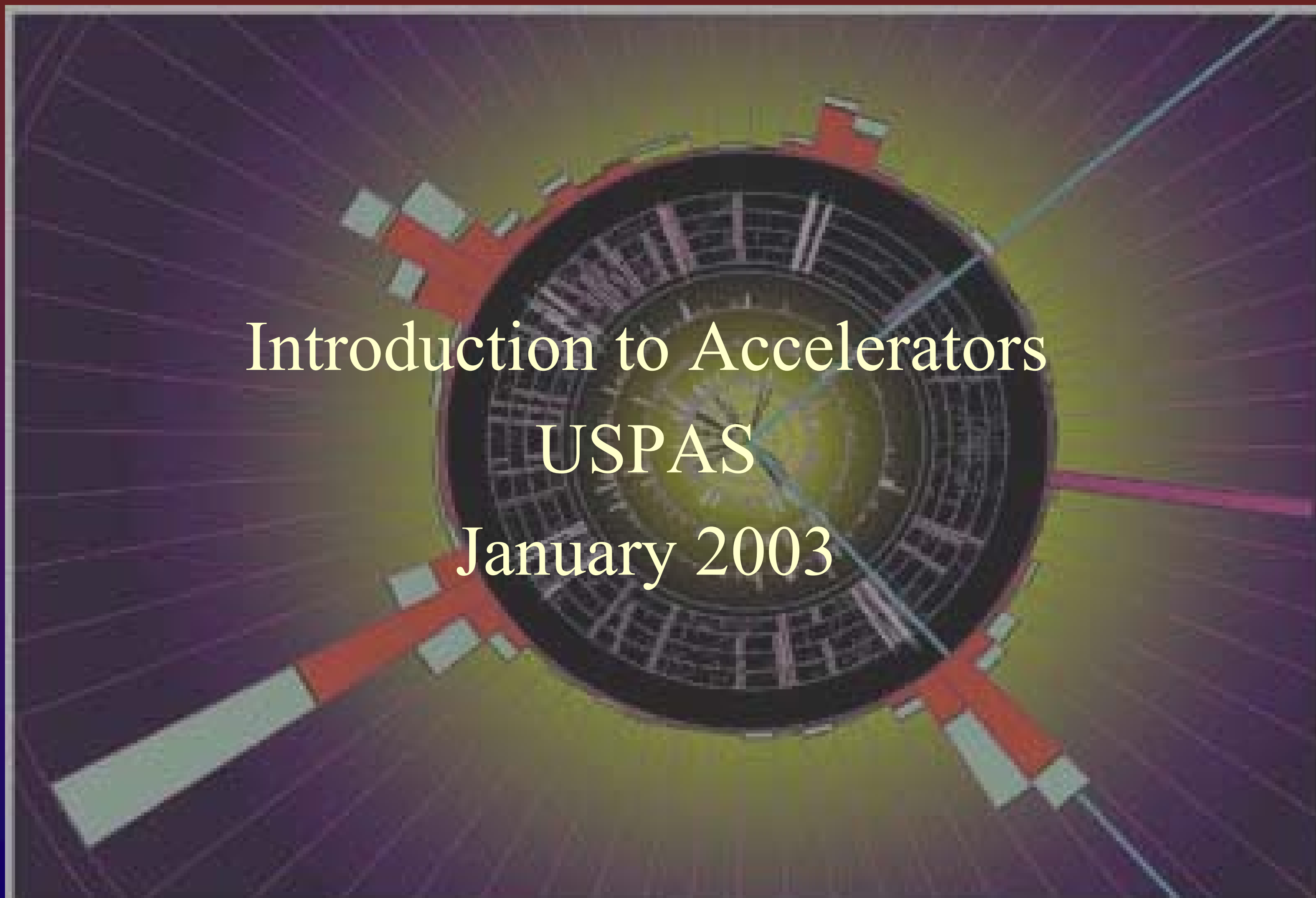
Foundations of Good Practice



Context

- One of the most important concepts to understand in working with safety systems is context.
  - Physical Environment
  - Regulatory Environment
  - Risk Environment
  - Management Structure
  - Resource Environment
- Without understanding the proper context of a safety system, tacit assumptions are made that could lead to undesired system behavior or worse.

Introduction to System Safety in Research Accelerators



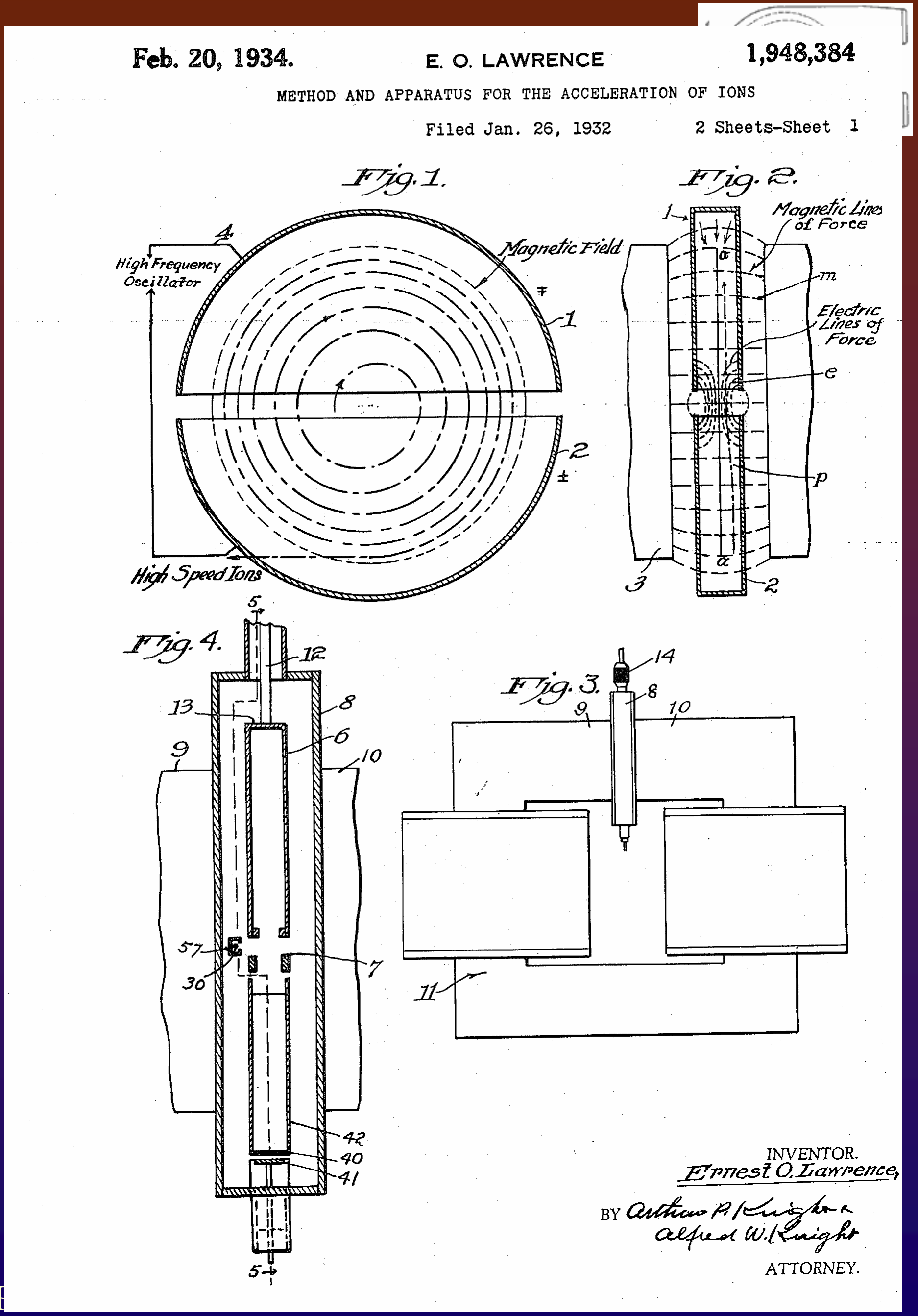
Introduction to Accelerators

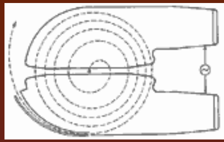
USPAS

January 2003

Accelerators

1934 Patent for the cyclotron awarded to E.O. Lawrence





Accelerator Basics

- Accelerators are used to transfer kinetic energy to charged particles.

$$\Delta E = qV$$

where

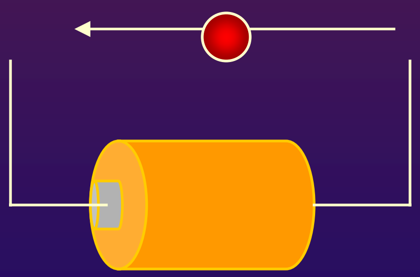
$$\Delta E = E_T - E_{rest}$$

- The energetic particles are used to transfer energy and momentum to nuclei in order to generate a myriad of ionizing radiation byproducts.

The eV

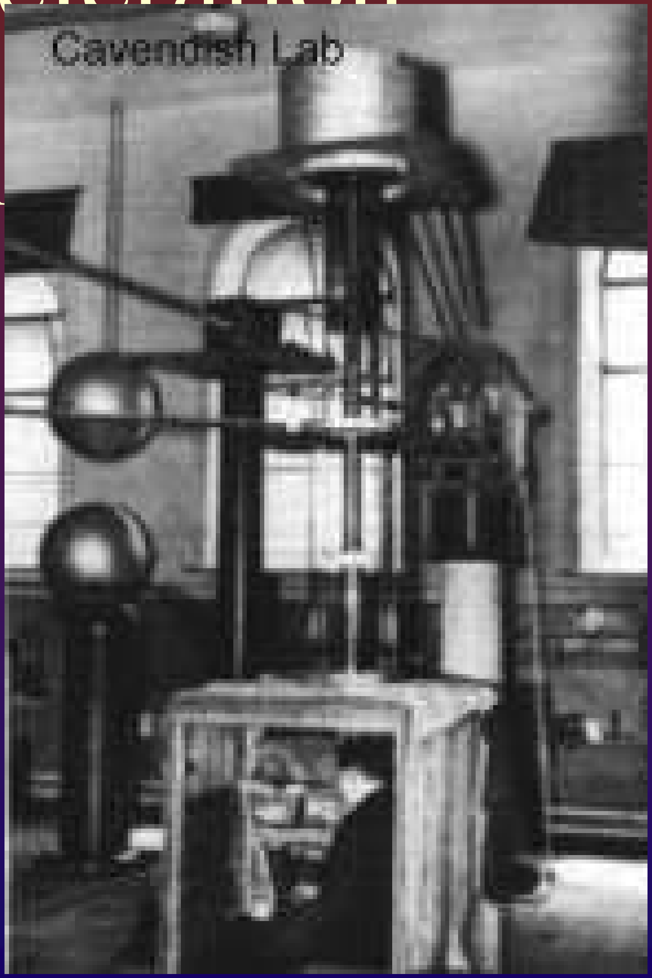
Energy equivalent to that gained by an electron passing through a potential difference of one volt.

$$
\begin{aligned}
1\,\mathrm{eV} &= 1.602\mathrm{x}10^{-19}\ \text{Joule}\ \left(\frac{kg\cdot m^2}{s^2}\right)\\
&= 1.602\mathrm{x}10^{-12}\ \text{ergs}\\
&= 4.451\mathrm{x}10^{-26}\ \text{kilowatt-hour}
\end{aligned}
$$



Electrostatic Acceleration

1932 photo of Cockcroft-Walton Accelerator.



Energy Gain as $v \Rightarrow c$

$$E = mc^2$$

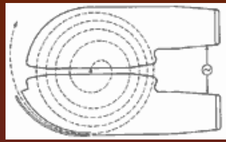
$$m = \frac{E}{c^2}$$

$$m = \frac{m_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

$$\beta = \frac{v}{c}$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

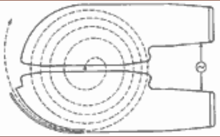
$$E = \gamma mc^2$$



Types of Accelerators

Use / Type	Collider	Fixed Target	Synchrotron Light	Free Electron Laser
Cyclotron				
Betatron				
Synchrotron				
Linac				
Recirculating Linac				

Accelerator Inventory



World wide inventory of accelerators, in total 15,000. The data have been collected by W. Scarf and W. Wiesczycka (See U. Amaldi Europhysics News, June 31, 2000)

Category	**Number**
Ion implanters and surface modifications	7,000
Accelerators in industry	1,500
Accelerators in non-nuclear research	1,000
Radiotherapy	5,000
Medical isotopes production	200
Hadron therapy	20
Synchrotron radiation sources	70
Nuclear and particle physics research	110

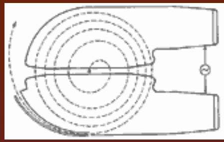
From Sven Kullander, Nobel e-museum, First published August 28, 2001
http://www.nobel.se/physics/articles/kullander/

Accelerated Particles

Particle	Symbol	Charge	Rest Mass, MeV	Spin
Electron/ Positron	e^-, e^+	-1,+1	0.511	½
Proton/Anit-Proton	$P, \overline{P}$	+1,-1	938	½
Heavy Ion	Atomic Symbol, Number	Varied	~939*Atomic number	½
Muon (not yet built)	μ	-1	106	½

Secondary Particle Beams

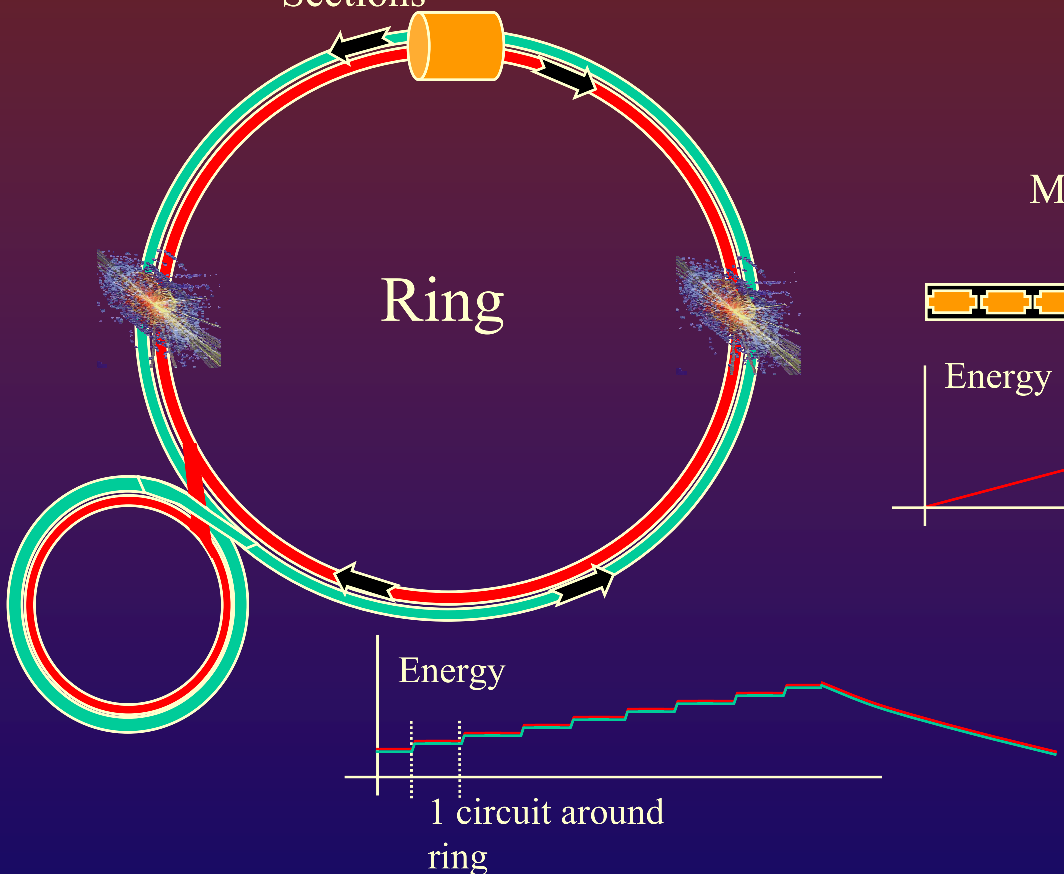
Particle	Symbol	
Photon	γ	FEL, Synchrotron Light, x -> far gamma
Neutron	n	Slow- irradiation Fast – therapy, spillation
neutrino	ν	Standard model
muon	$\mu^{+/-}$	Standard model
π-meson	$\pi^{+/-}$	Muon source, Therapy

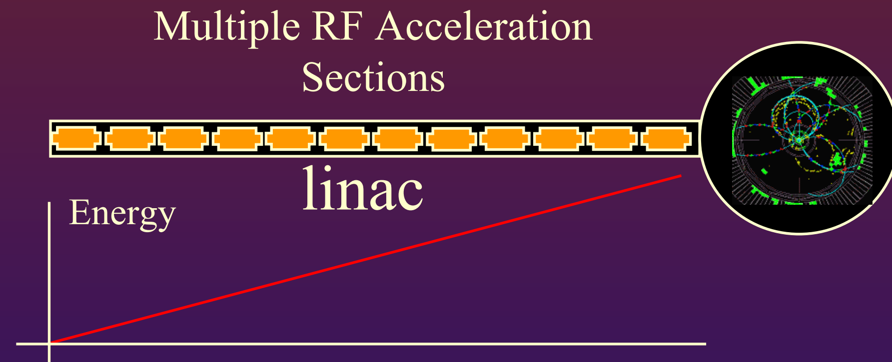


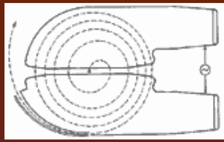
Common Accelerator Facility Units

- Source
  - Generates primary beam
  - Establishes timing structure
  - keV-MeV Energies
- Linear Accelerator (linac)
  - Many accelerator sections
  - Few magnetic steering sections
  - keV – 50GeV+
- Ring Accelerator
  - Few acceleration sections
  - Many magnetic steering sections
  - MeV-1TeV+
- Accumulator/Storage Ring
  - Accumulation of exotic particles
  - Particle storage
- Interaction Region
  - Target area
  - Collider area

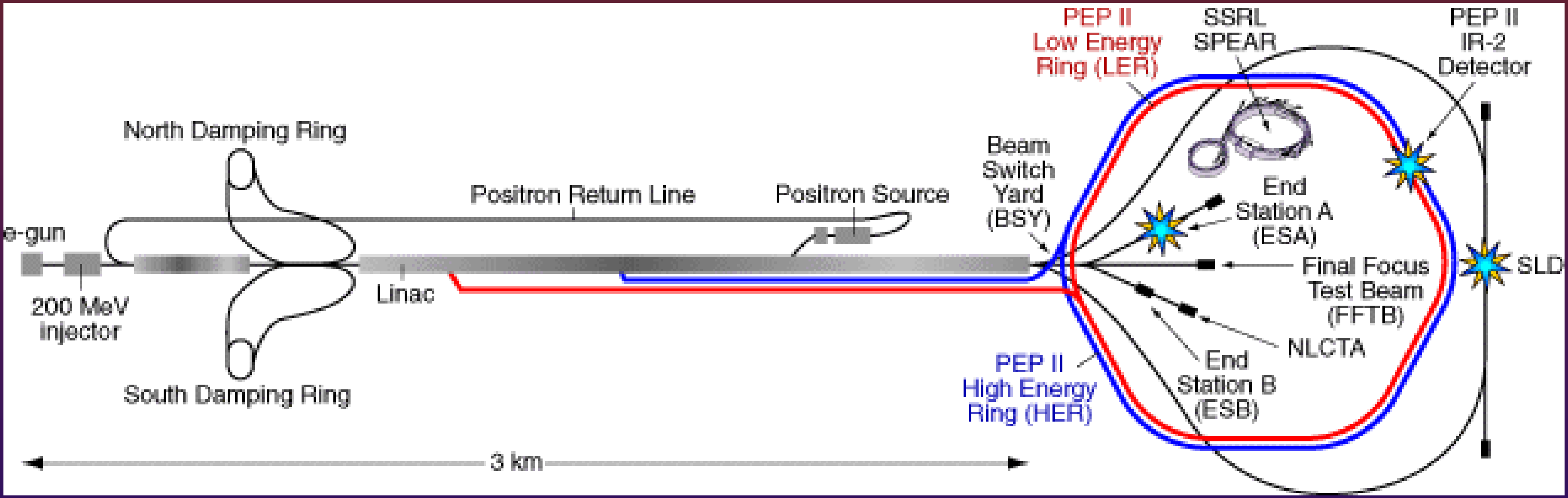
Ring vs. linac







SLAC



PEP II
Low Energy
Ring (LER)
SSRL
SPEAR
PEP II
IR-2
Detector
North Damping Ring
Beam
Switch
Yard
(BSY)
Positron Return Line
Positron Source
End
Station A
(ESA)
e-gun
Final Focus
Test Beam
(FFTB)
SLD
200 MeV
injector
Linac
NLCTA
PEP II
High Energy
Ring (HER)
End
Station B
(ESB)
South Damping Ring
3 km

Fermi

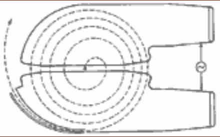
CERN

CERN aerial photo showing 27 km tunnel.

APS

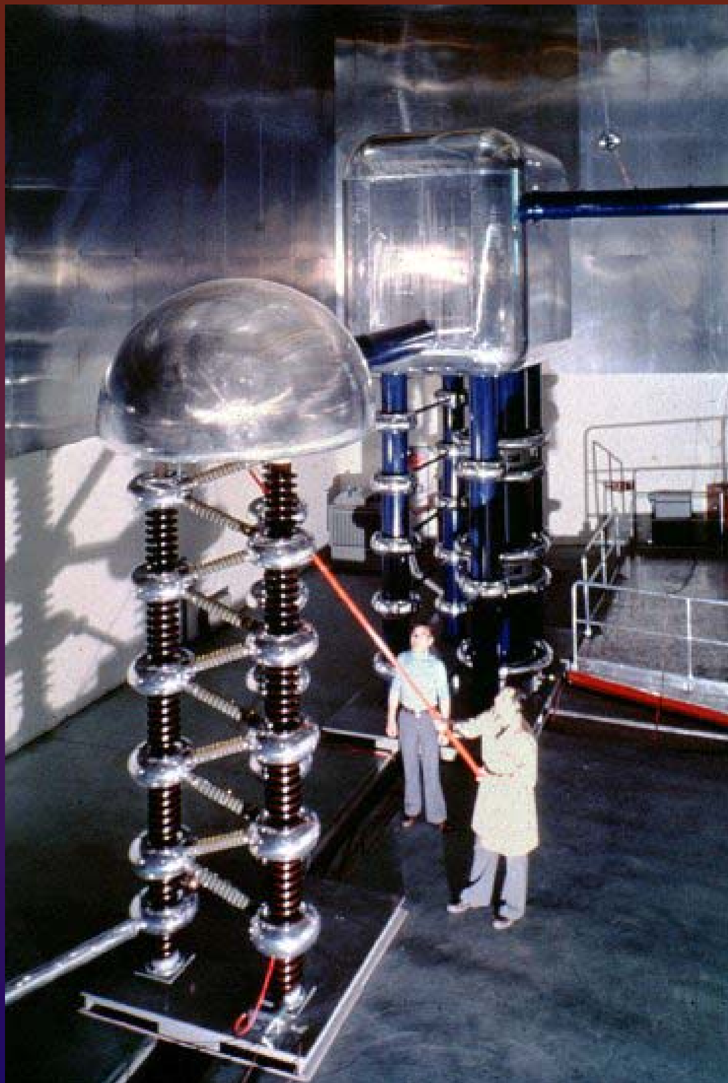
Advanced Photon Source, Aurora, IL.

Positron beam generates X-ray light as it circulates around the beam line.

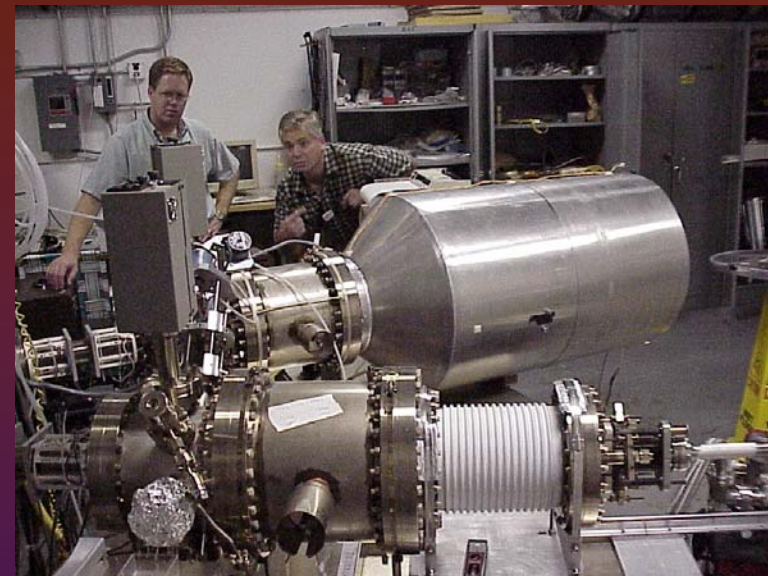


Basic Accelerator Systems

- Source
- Acceleration
- Beam Containment and Transport
- Beam Interaction and Dissipation

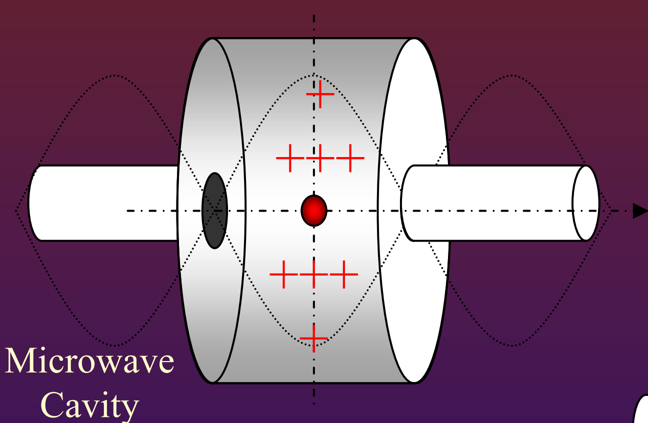


CERN 750keV Proton Source

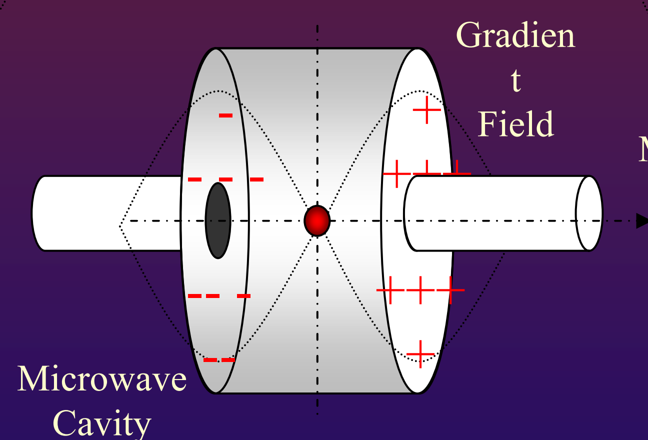


JLab 100keV Electron Source

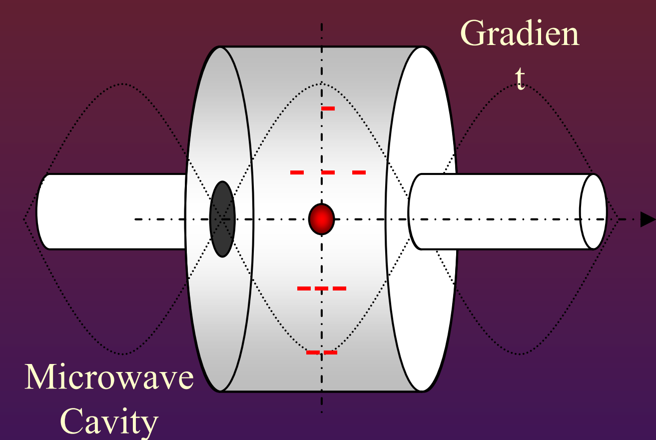
RF Acceleration



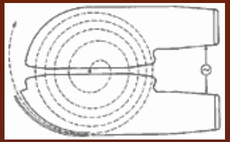
Negative Particle in
Accelerating Phase



Negative Particle
at Zero Phase

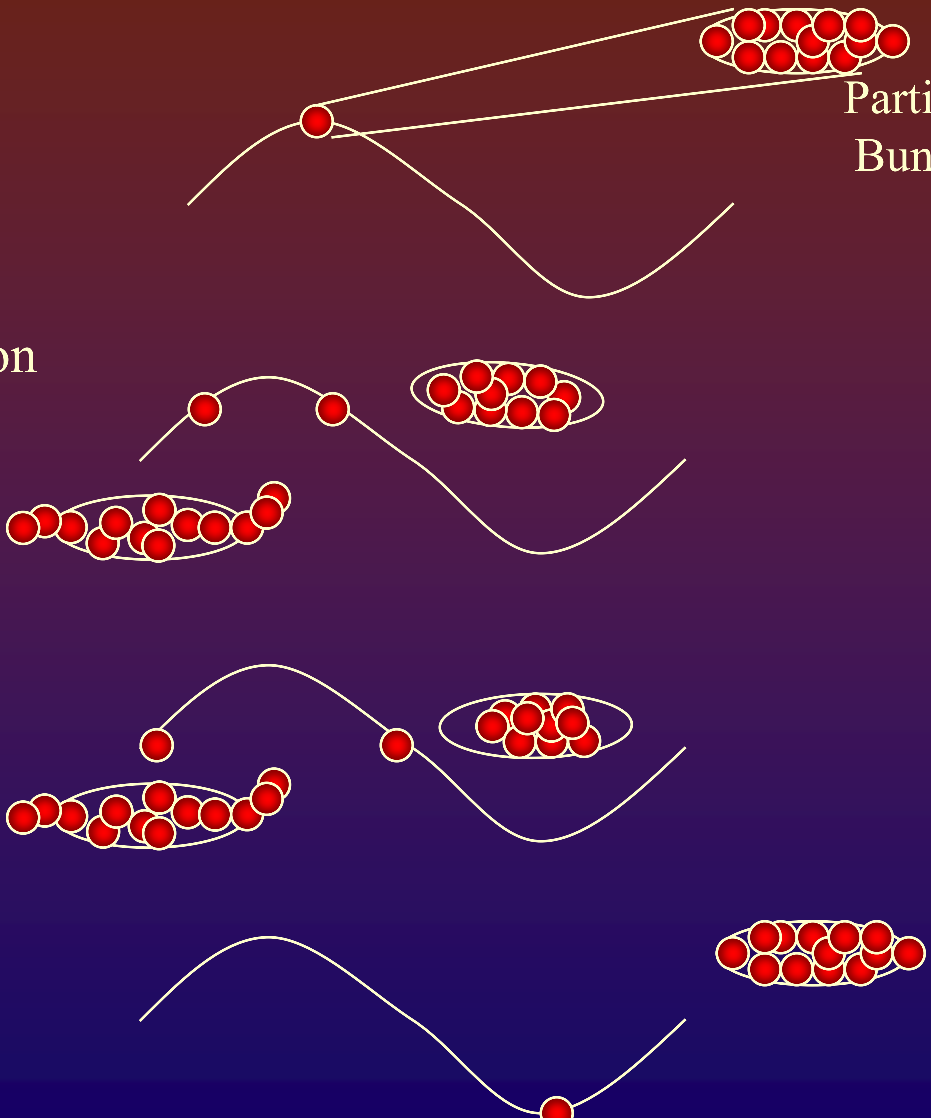


Negative Particle in
Decelerating Phase

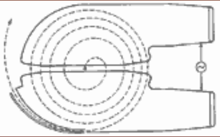


RF Acceleration

- On Accelerating Crest
  - Max Acceleration
- Off Crest
  - Different head-tail acceleration but still net acceleration
  - Bunching
  - Focusing
- Zero Crossing
  - Bunching
  - Make up Lost Energy
- On Decelerating Crest
  - Energy Recovery



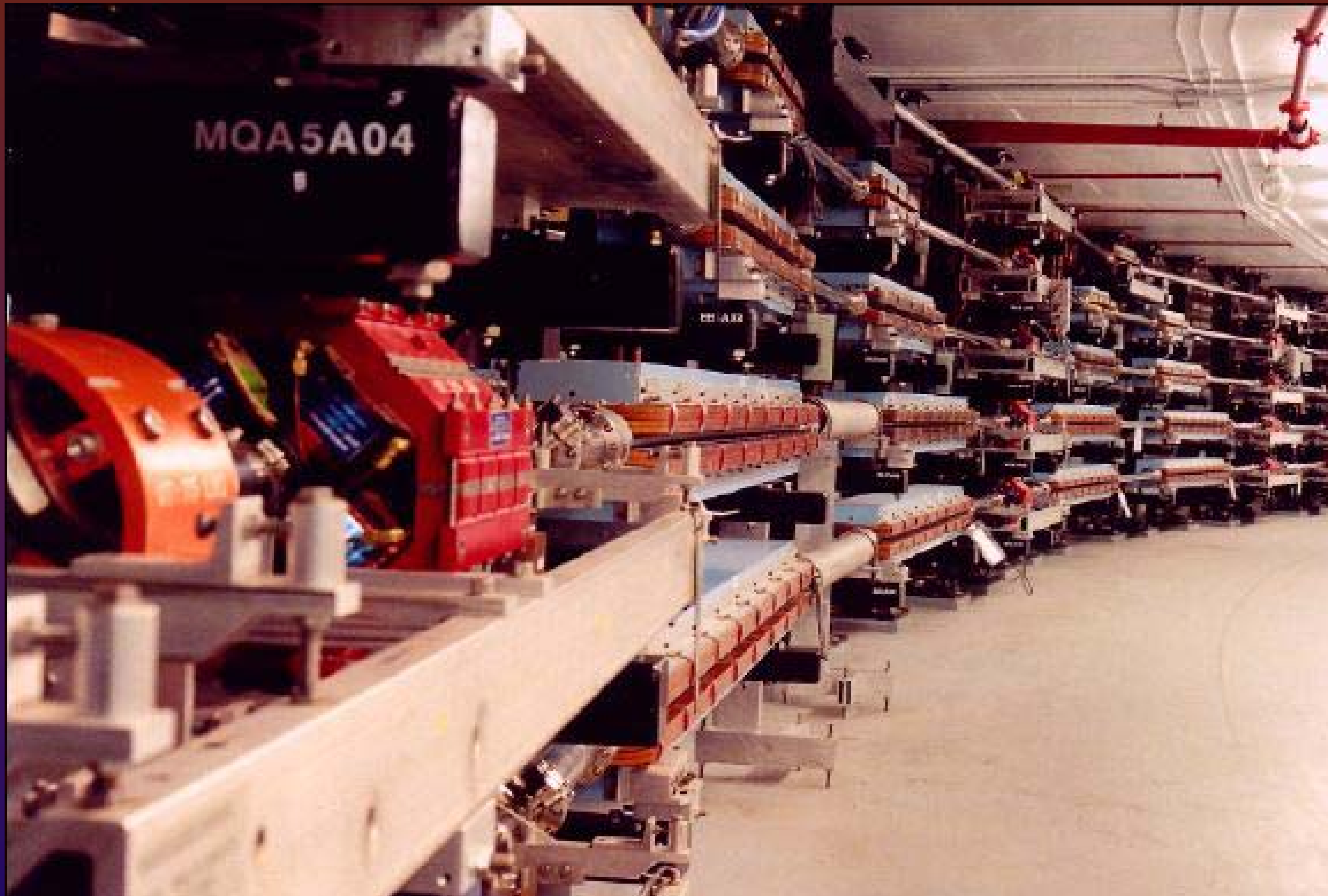
RHIC RF Cavities



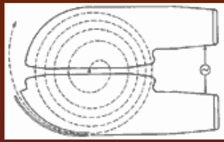
Field Emission and Multipacting

- Electrons are stripped off of cavity walls and accelerated within the cavity
- Can be accelerated into beam line (Dark Current)
- Source of radiation without beam
  - Field emission
    - Electrons emitted from surface irregularity
  - Multipacting
    - Electrons stripped off cavity material and impact adjacent walls in resonance with RF frequency

Beam Transport

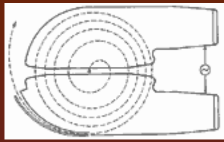


Jefferson Lab magnetic beam transport system showing dipoles (blue), quadrapole(red), and sextupole (orange) magnets.



Supporting Accelerator Systems

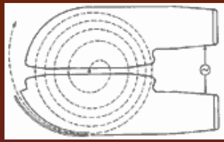
- Timing and Control
- Diagnostic
- Shielding
- Safety Systems
  - Access Control
  - Safety Interlock Systems
  - Alarm and Warning Systems



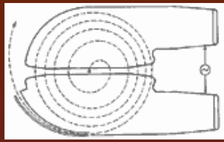
What's Ahead?

- High Power Photon Sources
- TESLA
- Neutrino factory
- CLIC
- ELIC/eRHIC
- LHC
- NLC
- Plasma/Laser Fusion
- JLab 12GeV
- Meson Scattering
- RIA
- Muon Collider

Special Safety Concerns for Accelerators



- Beam Production (Source)
  - Prompt ionizing radiation
    - Beam
    - Field Emission
    - Dark Current
    - Beam scraping
  - Laser systems, e.g photocathode
  - High Voltage
- Acceleration
  - Prompt ionizing radiation
    - Dark Current
    - Multipacting
    - Field Emission
    - Beam Scraping
  - Electromagnetic Radiation
  - High Voltage
  - Cryogenic Vessel
- Beam Transport
  - Prompt ionizing radiation
    - Beam Scraping
  - High Voltage
  - High Current
  - Laser Systems
  - Cryogenic Systems
  - Vacuum implosion
- Beam Interaction Area
  - Prompt ionizing radiation
  - High Voltage
  - High Current
  - Cryogenic Systems
  - Explosive Gas
  - Lasers
  - Vacuum implosion



Context

- In order to implement effective safety systems for accelerators, one must understand the context in which the system operates.
- This includes statutory, regulatory, and site specific requirements.
- It also includes a basic understanding of the equipment interfaced to the system.

- Ill defined requirements lead to:
  - Outright failure
  - Work arounds that are not as thoroughly evaluated as the original design
  - "complex" solutions; especially when using computer based systems
- One of the major causes of ill defined requirements is misinterpretation or misuse (or no reference to) regulatory requirements.